PCT/ SE 00 / 0 1 1 5 0

REC'D 11 JUL 2000
WIPO PCT

PRV

PATENT- OCH REGISTRERINGSVERKET
Patentavdelningen

SE00/01150

Intyg
Certificate

Härmed intygas att bifogade kopior överensstämmer med de handlingar som ursprungligen ingivits till Patent- och registreringsverket i nedannämnda ansökan.

This is to certify that the annexed is a true copy of the documents as originally filed with the Patent- and Registration Office in connection with the following patent application.

(71) Sökande / Applicant (s) — *RSO Corp NV, Curacao NL*

EJU

(21) Patentansökningsnummer / Patent application number — *9902196-6*

(86) Ingivningsdatum / Date of filing — *1999-06-09*

Stockholm, 2000-06-28

För Patent- och registreringsverket
For the Patent- and Registration Office

Leena Ullén

Leena Ullén

Avgift
Fee

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

PATENT- OCH REGISTRERINGSVERKET
SWEDEN

Postadress/Adress
Box 5055
S-102 42 STOCKHOLM

Telefon/Phone
+46 8 782 25 00
Vx 08-782 25 00

Telex
17978
PATOREG S

Telefax
+46 8 666 02 86
08-666 02 86

#90609 B:\PUBLIC\DOC\P\1505072.DOC DA/LJ

A TAG FOR ELECTRONIC ARTICLE IDENTIFICATION, A METHOD FOR ENCODING AN IDENTITY CODE INTO SUCH A TAG, AND AN APPARATUS FOR THE IDENTIFICATION THEREOF

Technical Field

The present invention relates to a tag for electronic article identification, comprising at least two magnetic elements representing an identity of the tag, or of an article to which the tag is attached, where the magnetic elements are electromagnetically detectable. The invention also relates to a method of encoding an identity code into such a tag, and to an apparatus for the identification thereof.

Description of the Prior Art

Many applications require a reliable and contactless detection of the presence, identity or position of objects within a detection zone. Common examples are for instance price labeling of commercial articles, identification of components in production lines, identification of material type at recycling plants or electronic article surveillance in e.g. shops.

For some applications it is sufficient to detect the presence of the object or article. One example is a simple electronic article surveillance system, which is arranged to provide an alarm signal, once a protected article is carried into a detection zone. Such a simple application uses a tag having one single sensor element in the form of a thin metal strip or wire with magnetic properties. The sensor element may be detected magnetically by means of arc-shaped magnetic generators/detectors, which expose the sensor element to an alternating magnetic field, that affects a physical property of the sensor element. Use is often made of the fact that the alternating magnetic field causes a periodical switch of the magnetic momentum of dipole of the sensor element, which is also known as

Barkhausen jumps. Tags of this kind are for instance disclosed in US-A-5 496 611, EP-A-0 710 923 and EP-A-0 716 393.

A different single-element tag technology is described in WO97/29463 and WO97/29464, wherein each tag comprises a wire-shaped element of amorphous or nano-crystalline metal alloy. An important feature of the amorphous or nano-crystalline metal alloy is that the permeability thereof may be controlled by an alternating magnetic modulating field. Through a physical effect known as Giant Magnetoimpedance, the amplitude of an electromagnetic reply signal from the tag is modulated by the magnetic modulating field, when the tag is excited by an electromagnetic interrogation signal. The modulation in amplitude of the reply signal is detected and used for determining the presence of the tag in the detection zone. A similar application is shown in WO98/36393, where very thin amorphous or nano-crystalline wires are used as sensor elements. These wires (also known as microwires) have a diameter of less than 30 μm, preferably 5-15 μm.

None of the electronic article surveillance applications described above provides a remotely detectable identity for each tag. However, for advanced applications it is necessary to provide such identity information, representing e.g. an article number, serial number, material code, etc., for the respective object, to which each tag is attached. In a different technical field, such identity information is provided by barcodes (such as EAN), i.e. a printed pattern of black and white lines, which is scanned by an optical reader. Optical barcode tags have an advantage in that they offer a wide codespan - an EAN barcode may for instance represent a 12-digit article number, thereby theoretically providing a codespan of 10^{12} different barcode values. Optical article identification systems have a distinct drawback, however, in that the

operating distance thereof is quite restricted; the barcode tag will have to pass in close proximity with the optical reader for allowing a successful reading of the barcode. Furthermore, since the barcode is read by optical means, the tag must be attached to a visible surface portion of the article in question.

A non-optical system with longer operating range is disclosed in WO88/01427, wherein the tag or marker is provided with a number of sensor elements in the form of magnetostrictive strips or ribbons made of an amorphous ferromagnetic material and arranged in predetermined angular relationships or at predetermined distances from each other. The identity of such a tag is represented by the predetermined relationships as well as the respective type of individual sensor elements. The sensor elements are excitable to mechanical resonance by magnetic energy. The magnetic signals generated by the resonating sensor elements may be detected magnetically or inductively. Compared to optical barcode systems, the tag of WO88/01427 provides a significantly more limited codespan.

A similar system is described in WO93/14478, wherein the tag or markers are provided with a number of electrical resonant circuits, each of which is inductively coupled to a respective magnetic sensor element. Each electrical resonant circuit is excited to oscillate electrically, and the resonant frequency thereof is controllable, through the permeability of the magnetic element, by an external magnetic field, wherein a simultaneous detection of several identical tags is made possible.

In summary, prior art tags for remote non-optical detection of objects are either of a single-element type, allowing only the presence of each tag to be detected, or of a multi-element type, allowing also an identity of each tag to be detected. Single-element tags are easier to design and produce and therefore have a lower unit cost. On

the other hand, multi-element tags require a supporting carrier (particularly for mechanically resonating sensor elements) and/or capacitive and inductive components (for the electric resonant circuit versions). Naturally, this implies a higher cost per unit. Furthermore, the codespan (number of different code values) of the multi-element tags described above is clearly inferior in comparison with optical barcode tags. Additionally, since the multi-element tags mainly operate by magnetic or inductive link, the operating distance of the detection system is quite narrow (although better than for optical barcode systems).

Summary of the Invention

An objective of the present invention is to provide a tag for electronic article identification, which is capable of providing a large codespan, may be read from a long distance by non-optical means, and may be manufactured at very low cost. More specifically, the invention aims at providing a tag, which combines the good characteristics of optical barcode tags (large codespan) and non-optical multi-element tags (long operating distance) at a very low price per tag.

The invention is also aimed at a method of encoding an identity into such a tag, and an apparatus for identifying the tag.

The objectives have been achieved by the provision of a tag, a method, and an apparatus, which resemble the ones described in aforesaid WO97/29463, WO97/29464, and WO98/36393 (i.e., use electromagnetic excitation and detection, and a magnetic field for modulating the reply signal from the tag), where each tag is provided with at least two thin magnetic wire-shaped elements of an amorphous or nano-crystalline metal alloy for representing an identity of the tag. The sensor elements are available in different predetermined lengths and in different predetermined dia-

meters. A number of individual sensor elements are selected and arranged in a predetermined angular relationship in the tag. The identity of the tag is represented by a code, which is formed by the length and diameter of each individual sensor element, and by the angles between sensor elements.

Other objectives, features and advantages of the present invention appear from the following detailed disclosure, from the drawings as well from the appended patent claims.

Brief Description of the Drawings

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings, in which:

FIG 1 illustrates an article identification apparatus, in which the tag and method according to the present invention may be applied,

FIG 2 is a schematic planview of a preferred embodiment of a tag according to the invention, where the magnetic elements have different lengths, different diameters and are arranged at respective angles to each other, and

FIGs 3-5 are flow charts illustrating the principle, according to which the apparatus of FIG 1 operates in order to identify the tag of FIG 2.

Detailed Disclosure of the Invention

FIG 1 illustrates an article identification apparatus for detecting a tag 30 attached to an object 20, and for determining an identity thereof. A transmitter antenna 11 and a receiver antenna 12 are arranged in a detection zone 10. The transmitter antenna 11 is operatively connected to an output stage 13, which in turn is connected to a controller 14. The output stage comprises various commercially available driving and amplifying circuits and means for

generating an alternating electric current of high frequency f_{HF}, said current flowing back and forth through the transmitter antenna 11 when supplied thereto, wherein a high-frequency electromagnetic field is generated around the transmitter antenna. This electromagnetic field is used, as will be described in more detail below, for exciting the tag 30 within the detection zone 10, so that the tag will transmit, at the reception of a first electromagnetic signal 50 from the transmitter antenna 11, a second electromagnetic signal 60, which is received by the receiver antenna 12 and transformed into a corresponding electric signal 70.

The receiver antenna 12 is operatively connected to an input stage 15, which comprises conventional means with amplifying and signal processing functions, such as band-pass filtering and amplifying circuits. The input stage 15 also comprises means for demodulating the received signal 70 and supplying it, as a reply signal 80, to the controller 14.

The transmitter antenna 11 as well as the receiver antenna 12 thus have the purpose of converting, in a known way, between an electrical signal of high frequency and an electromagnetic signal. Preferably, the antennas are helically formed antennas with rotating polarization (for optimal coverage in all directions), or alternatively conventional end-fed or center-fed halfwave whip antennas, but other known antenna types are equally possible.

The detection zone 10 is additionally provided with means 16, such as a coil, for generating a magnetic modulating field H_{mod}. The means 16 is connected to the controller 14 via a driving stage 17. The driving stage 17 comprises means for generating a modulating current, which is supplied to the means 16, wherein the magnetic modulating field H_{mod} is generated in essential portions of the detection zone 10. The magnetic modulating field H_{mod} may

have a frequency of about 500-800 Hz, and the electromagnetic excitation and reply signals may have a frequency within the GHz band, such as 1.3 GHz or 2.45 GHz. Frequencies outside these ranges are however also possible.

As described above, the object 20, which has been schematically illustrated in FIG 1 in the form of a box-shaped package, is provided with the tag 30 according to the invention, comprising at least two magnetic sensor elements 31-36 (FIG 2), which are arranged in a mutual relationship and represent an identity of the tag 30, or of the object 20, to which the tag is attached. The sensor elements are electromagnetically detectable and comprise a magnetic material, the permeability of which is controllable by a magnetic field and the high-frequency impedance of which depends on said permeability, according to an effect commonly known as Gigant Magneto-Impedance. This effect causes a modulation in amplitude of the second electromagnetic signal 60 transmitted from the tag 30 and received by the receiver antenna 12 as the signal 70. The amplitude is modulated by the magnetic modulating field H_{mod}.

A system similar to the apparatus described above is thoroughly disclosed in WO97/29463, WO97/29464, and WO98/36393, all of which are fully incorporated herein by reference.

A preferred embodiment of the tag 30 is illustrated in FIG 2. The tag 30 comprises a tag body 38, such as a thin sheet of paper or plastics, onto which six sensor elements 31-36 are mounted by e.g. adhesion. Alternatively, the six elements 31-36 may be directly integrated into the material of the object 20, as will be described in more detail below.

The material of the sensor elements 31-36 is essentially identical to the ones described in the above-mentioned WO98/36393. In other words, in the embodiment of

FIG 2, the sensor elements 31-36 are made from a cobalt-rich amorphous metal alloy, such as $(Fe_{0.06}Co_{0.94})_{72.5}Si_{12.5}B_{15}$. The sensor elements are formed as very thin metal wires with respective lengths between 40 and 100 mm and respective diameters between 10 and 100 µm. An important feature of the invention is that the individual elements 31-36 have different and predetermined lengths L_1-L_6 as well as different and predetermined diameters ϕ_1- ϕ_6, which will be described in more detail below.

Optionally, the wires may be provided with a thin coating of glass or another dielectric material, the thickness of which is preferably less than the thickness (diameter) of the metal wire core. Such a wire is commonly referred to as a **microwire** and is produced by rapidly pulling a molten metal alloy and a surrounding molten glass tube.

Alternatively, the material of the sensor elements 31-36 may be nanocrystalline rather than amorphous. Furthermore, the glass coating may be dispensed with, and the thickness (transversal diameter) of the elements (wires) may be larger than for the preferred embodiment. Transversal diameters of between 100 and 200 µm have proven useful, particularly about 125 µm, as shown in WO97/29463 and WO97/29464. However, such wires are not referred to as microwires and are produced in other ways than the one mentioned above, as is well known per se in the technical field of magnetic sensor elements. In summary, the tag of the present invention may comprise magnetic sensor elements of various kinds, as defined by the appended independent tag claim.

According to the embodiment of FIG 2, the six sensor elements 31-36 are arranged at a certain angle α_1-α_6 to each other. As previously mentioned, the sensor elements 31-36 may be mounted to a carrier 38, such as an adhesive label, or alternatively attached directly to the related

object 20, for instance by adhesion. A further alternative is to sew or weave the sensor elements into or onto e.g. an article of clothing or another article of merchandise. In such a case the identity of the sensor may represent an article number, class or type. Yet another alternative is to integrate the sensor elements into a packaging material, such as cardboard, paper or plastic film, or into an article of recycling (e.g. a plastic container, a glass bottle, a cardboard package, etc.). In such cases, the identity of the sensor may represent e.g. a type of material for each recycling article.

The identity of the tag 30 (or, more precisely, its related object 20) is provided by the element lengths, diameters and the angular deviations between the sensor elements 31-36. These parameters jointly form an identity code of the tag, as will be described in more detail below.

From an overall point of view, the basic inventive idea is to create an article identification tag by using a predetermined number of magnetic sensor elements in the form of amorphous microwires. An identity code for the tag is formed by using the following three microwire properties as code parameters:

- length
- diameter
- angle

According to the invention, the magnetic sensor elements are provided in L different lengths and D different diameters. Moreover, A different angular positions are provided on the tag 30. All individual element lengths, element diameters and angular positions are predetermined and well-defined.

From the L different element lengths and D different element diameters, (LxD) unique element types are formed, which are referenced from 0 to (LxD-1). In other words, each element type is given a respective value ranging from

0 to (LxD-1). For each angular position, an element of a specific element type (among said LxD types) is selected and arranged on the tag. Having done this, an identity code is provided, which may be viewed upon as comprising a plurality of words at respective positions in a numeral system. The base of this numeral system is neither decimal nor binary but LxD. The different positions in the code is represented by the different angular positions on the tag. Hence, each angular position represents a respective numerical position in the code, and the type of the respective element represents the value at the respective code position.

The above will be better understood by the following practical example, which refers to FIG 2. FIG 2 illustrates a tag 30, which is capable of storing an identity code having a code span as wide as for a conventional EAN barcode. Such an EAN barcode comprises 12 words, each containing a value between 0 and 9. This provides a code span of 10^{12} different codes.

By setting: L=10, D=10, A=6,

$(LxD)^A = 100^6 = 10^{12}$ different code values are obtained for the tag 30 of FIG 2. Therefore, the identity code of tag 30 is compatible with an EAN barcode. As shown in FIG 2, each magnetic sensor element 31-36 is chosen among any of LxD = 100 different types, referenced from 0 to 99. Moreover, the six elements 31-36 are arranged in six different angular positions α_1-α_6. For the identity code of FIG 2, the following sequence of angular positions is used:

α_1 30°
α_2 30°
α_3 30°
α_4- 30°
α_5- 40°
α_6- 20°

The EAN code 068320160108 is represented by the tag 30 of FIG 2. The relation between this EAN code and the identity code of tag 30 is as follows:

EAN base	10^{11} 10^{10}	10^{9} 10^{8}	10^{7} 10^{6}	10^{5} 10^{4}	10^{3} 10^{2}	10^{1} 10^{0}
EAN word	0 6	8 3	2 0	1 6	0 1	0 8
Tag base	100^{5}	100^{4}	100^{3}	100^{2}	100^{1}	100^{0}
Tag word	6	83	20	16	1	8
Angular pos.	α_1	α_2	α_3	α_4	α_5	α_6
Element No.	31	32	33	34	35	36

A different EAN code will be represented by different element types (values between 0 and 99) for the elements 31-36. Observe, however, that the angular positions α_1-α_6 will <u>not</u> change but remain identical to the angular sequence specified above. Instead, a different angular sequence for angles α_1-α_6 may be chosen, in case another *kind* of identity code is to be represented, not another code *value* of the same type of code.

FIGs 3-5 illustrate the way in which the article identification apparatus of FIG 1 operates in order to detect and read the identity code of the tag 30 shown in FIG 2. Firstly, the magnetic modulating field H_{mod}, as generated by the coil 16, is varied according to the following function:

$H_{mod} = [H_0 + H_{ac}\sin(\omega_m t)]\cos(\alpha_H)$, where:

H_0 is the amplitude of a time-invariant (DC) component of the magnetic modulating field H_{mod},

H_{ac} is the amplitude of a time-variant (AC) component of the magnetic modulating field H_{mod},

ω_m is the angular frequency of the magnetic modulating field H_{mod}, and

α_H is an orientation of the magnetic field vector of the magnetic modulating field H_{mod}.

The EAN code 068320160108 is represented by the tag 30 of FIG 2. The relation between this EAN code and the identity code of tag 30 is as follows:

EAN base	10^{11} 10^{10}	10^{9} 10^{8}	10^{7} 10^{6}	10^{5} 10^{4}	10^{3} 10^{2}	10^{1} 10^{0}
EAN word	0 6	8 3	2 0	1 6	0 1	0 8
Tag base	100^{5}	100^{4}	100^{3}	100^{2}	100^{1}	100^{0}
Tag word	6	83	20	16	1	8
Angular pos.	α_1	α_2	α_3	α_4	α_5	α_6
Element No.	31	32	33	34	35	36

A different EAN code will be represented by different element types (values between 0 and 99) for the elements 31-36. Observe, however, that the angular positions α_1-α_6 will <u>not</u> change but remain identical to the angular sequence specified above. Instead, a different angular sequence for angles α_1-α_6 may be chosen, in case another *kind* of identity code is to be represented, not another code *value* of the same type of code.

FIGs 3-5 illustrate the way in which the article identification apparatus of FIG 1 operates in order to detect and read the identity code of the tag 30 shown in FIG 2. Firstly, the magnetic modulating field H_{mod}, as generated by the coil 16, is varied according to the following function:

$H_{mod} = [H_0 + H_{ac}\sin(\omega_m t)]\cos(\alpha_H)$, where:

H_0 is the amplitude of a time-invariant (DC) component of the magnetic modulating field H_{mod},

H_{ac} is the amplitude of a time-variant (AC) component of the magnetic modulating field H_{mod},

ω_m is the angular frequency of the magnetic modulating field H_{mod}, and

α_H is an orientation of the magnetic field vector of the magnetic modulating field H_{mod}.

The general procedure performed by the apparatus of FIG 1 is as follows. The magnetic modulating field is given a varying orientation, i.e. the field vector thereof is rotated from 0° to 360° (α_H). The purpose of this angular scanning is to sequentially detect the respective angles, at which the magnetic sensor elements are present. It is to be observed that the tag 30 may have an arbitrary and typically unknown orientation within the detection zone 10. Therefore, the absolute angular positions of the magnetic sensor elements 31-36, with respect to the orientation α_H of the magnetic modulating field H_{mod}, is not initially known but have to be determined according to an algorithm, which is shown in more detail in FIG 4.

Referring to FIG 3, the following steps are performed for reading the identity code of tag 30. First, in a step 100, the angle α_i of a first microwire (magnetic sensor element) is determined. In a subsequent step 200, the length L_i of that element is determined, and in a step 300 the diameter ϕ_i thereof is determined. Upon termination of step 300, all three relevant parameters α_i, L_i and ϕ_i (angle, length and diameter) have been determined for element i. These values are saved by the controller 14 in a step 400. In a step 500, it is determined whether the orientation α_H of the magnetic modulating field H_{mod} is less than 360°. If the answer is in the affirmative, the angle α_H is increased in a step 600, and the control is returned to the beginning of step 100, wherein the angle α_{i+1} of a second element i+1 is determined in step 100, the length L_{i+1} thereof is determined in step 200 and the diameter ϕ_{i+1} is determined in step 300.

In this way, steps 100, 200, 300, 400, 500 and 600 are repeated for all six elements 31-36, until the angle of rotation α_H of the magnetic modulating field H_{mod} reaches 360°. In a step 700, parameters α_i, L_i and ϕ_i, where i = 1...6, have been determined for all magnetic sensor

elements 31-36. In a last step 800, the determined parameters are transformed into a final identity code of tag 30 by the controller 14. To this end, the controller 14 combines the length and diameter of each individual element and determines the corresponding element type (from 0 to 99) by consulting defined data in e.g. a look-up table stored in memory. Then, since the angular sequence of the angles α_1-α_6 is well-defined, the controller 14 is capable of mapping the individual element types to the correct angular position α_1-α_6. Finally, the determined element types are inserted into the respective position (as determined by the angular position), in the identity code, and the final identity code thus determined may be provided as output from the controller to an external device, such as a computer, a cash register, etc.

In FIG 4, the angle determination step 100 is illustrated in more detail. In essence, the details of the angle determination procedure 100 are disclosed in the Swedish patent application 9802221-3, having the title "A sensor, a method and a system for remote detection of objects" and a filing date of 18 June 1998. Said patent application is fully incorporated herein by reference. In summary, the angle determination procedure 100 is based on a distinct frequency shift, which occurs in the reply signal 80, when the magnetic sensor element is momentarily exposed to a time-invariant (DC) component of zero value. Typically, this happens when the magnetic field of the earth balances the momentary orientation of the time-invariant component of H_{mod}. At this moment, the frequency of the reply signal 80 shifts to a double value. Hence, as shown in FIG 4, the time-invariant component H_0 is rotated by the incrementing of α_x (see step 110). In a step 120, the frequency of the reply signal 80 is monitored by the controller 14. In a step 130, it is determined whether the above characteristic frequency shift to a double frequency

is detected in the reply signal 80. If the answer is in the affirmative, then the angular position α_i of element i has been found and is given by the momentary value of α_H. Otherwise, the control is returned to the beginning of step 110, and the time-invariant component H_0 is further rotated.

Referring now to the lower part of FIG 4, the length determination procedure 200 is illustrated in more detail. As described more thoroughly in the Swedish patent application labelled "A method, a system and a sensor for remote detection of objects, and a method for determining a length of a magnetic element", filed on the same date as the present application and fully incorporated herein by reference, the length of a thin magnetic wire shaped element of an amorphous or nano-crystalline metal alloy, such as microwires, may be determined by the following steps. The amplitude of the magnetic modulating field H_{mod} is varied in a well-defined way, and a corresponding variation in amplitude is detected for the reply signal 80 from the tag 30. The length of individual magnetic sensor elements 31-36 may then be determined through a magnetic property of the element, known as the demagnetizing factor. The demagnetizing factor represents the intrinsic magnetization of the magnetic element in relation to an external magnetic field and depends, inter alia, on the length and the cross-sectional area of the element, as set out below.

Assuming that the magnetic sensor element is a wire having a length c and a diameter a, the longitudinal demagnetizing factor N_c of the element may be expressed as:

$$N_c = \frac{4\pi}{r^2-1}\left[\frac{r}{\sqrt{r^2-1}}\ln\left[r+\sqrt{r^2-1}\right]-1\right],$$

where $r = c/a$.

The transverse demagnetizing factor N_a may be obtained through the expression:

$$N_c + 2N_a = 4\pi .$$

As previously described, the impedance of the magnetic element will depend on the permeability of the element, and when the permeability is varied by way of the magnetic modulating field, the impedance will vary accordingly, and, ultimately, the amplitude of the electromagnetic reply signal will be modulated by the magnetic modulating field.

The energy of the amplitude modulation will depend not only on the amplitude of the magnetic modulating field but also on the high-frequency (HF) energy of the electromagnetic excitation signal and on the length of the element. The reason why the length will have an influence on the amplitude modulation energy is because the amplitude modulation is due to the permeability, which in turn depends on the demagnetizing factor, which, ultimately, depends on the length of the element, as appears from the formula above.

Consequently, by increasing the amplitude of the magnetic modulating field, the amplitude modulation energy of the reply signal will increase according to an essentially linear factor, which depends on the length of the element. More specifically, a longer magnetic sensor element, such as element 32 in FIG 2, will exhibit a stronger dependence on the variation in amplitude of the magnetic modulating field H_{mod}, than a shorter element 33.

Referring back to the length determination procedure 200 of FIG 4, the length L_i of an individual magnetic sensor element 31-36 is determined as follows. The amplitude H_{ac} of the time-variant component of the magnetic modulating field H_{mod} is varied from a first value to a second value in a first step 210, i.e. by increasing the

amplitude by a value ΔH_{ac}. In step 220, the amplitude A of the demodulated reply signal 80 is determined for the first and second amplitudes of the magnetic modulating field H_{mod}, i.e. the change ΔA in amplitude of the reply signal is determined in response to the change ΔH_{ac} in amplitude of the magnetic modulating field H_{mod}. Then, a linear relation K_1 is calculated as $K_1 = \Delta A/\Delta H_{ac}$ in step 230. Since there is a predetermined relationship between the linear relation K_1 and the length L_1 of the magnetic element, the length may be calculated from the determined relation $K_1 = \Delta A/\Delta H_{ac}$. Preferably, the controller 14 is provided with a memory for storing cross-reference data for determining the lengths L_1 from the linear relations K_1.

Referring now to FIG 5, the diameter determination procedure 300 is illustrated in more detail. The Swedish patent application 9900119-0, which was filed on 18 January 1999 and is fully incorporated herein by reference, discloses a detection method and device for detecting the diameter of a thin wire-shaped conductor, such as a micro-wire. The diameter determination procedure 300 operates according to the principles set out in the above patent application and is based on the variation of impedance inside a conductor for high-frequency electric signals. This well-known phenomenon is often referred to as the skin-depth effect and may be summarized according to the following. The penetration depth of electric currents inside the conductor depends on the frequency of the electric signal, of the electrical resistivity of the conductor as well as of the magnetic permeability thereof. The penetration depth or skin depth δ may be calculated according to the formula:

$\delta = 1/(\pi f \mu \sigma)^{½}$, where

f = the frequency of the electric current,

$\mu = \mu_0 x \mu_r$ is the permeability of the conductor, and

σ is the conductivity of the conductor material.

When looking at the above formula, it is obvious that the skin depth δ will decrease, when the denominator of the formula increases. In response, also the value of the impedance of the conductor will decrease. A minimum value of the impedance will be reached, when the skin depth δ equals the radius of the wire-shaped conductor. After this point, which will be referred to as the "saturation point" below, the impedance will not change, even if the skin depth increases further.

Now, referring back to FIG 5 as well as the apparatus shown in FIG 1, since the magnetic sensor elements 31-36 is made of an amorphous material, their permeability μ is influenced by the magnetic modulating field H_{mod}. Therefore, by incrementing, in a step 310, the amplitude of the time-variant component H_{ac} of the magnetic modulating field H_{mod}, the skin depth δ and, accordingly, the impedance of the magnetic sensor element and, ultimately, the amplitude of the reply signal 80 will vary accordingly. Simultaneously, in step 320, the amplitude of the reply signal 80 will be monitored in search of the saturation point, where the amplitude stops varying in response to the increased H_{ac}. When the saturation point has been reached, the diameter ϕ_i of the magnetic sensor element i is determined by reading the momentary value of H_{ac}, referred to as H_{ac_sat} below. Initially, for a reference wire having a well-known diameter ϕ_{ref}, the corresponding value H_{ac_ref} of the magnetic modulating field has been determined at the saturation point. Now, in step 330, the diameter ϕ_i of the magnetic sensor element i is determined as $\phi_i=\phi_{ref}(H_{ac\_sat}/H_{ac\_ref})$

The present invention has been described above by way of a few exemplary embodiments. However, other embodiments than the ones described above are possible within the scope of the invention, as defined by the appended independent patent claims.

CLAIMS

1. A tag (30) for electronic article identification, comprising at least two magnetic elements (31-36) representing an identity of the tag, or of an article (20) to which the tag is attached, said magnetic elements being electromagnetically detectable, **characterized** in that

the magnetic elements (31-36) are formed as wires made from an amorphous or nano-crystalline metal alloy;

the magnetic elements (31-36) are arranged at predetermined angles (α_1-α_6) to each other;

at least one of the magnetic elements (31-36) has a length (L_1-L_6), which is different from the length of at least one other magnetic element of the tag;

at least one of the magnetic elements (31-36) has a diameter (ϕ_1-ϕ_6), which is different from the diameter of at least one other magnetic element of the tag;

wherein the lengths and diameters of the magnetic elements, and the angles between them, jointly form the identity of the tag.

2. A tag according to claim 1, wherein the diameters (ϕ_1-ϕ_6) of the magnetic elements (31-36) are selected from a range between 10 and 100 µm.

3. A tag according to claim 1, wherein the lengths (L_1-L_6) of the magnetic elements (31-36) are selected from a range between 40 and 100 mm.

4. A tag according to any of claims 1-3, wherein each magnetic element (31-36) is provided with a coating of dielectric material, such as glass.

5. A tag according to any of claims 1-4, wherein the amorphous or nano-crystalline metal alloy of each magnetic element (31-36) exhibits a Giant Magnetoimpedance-effect

when exposed to electromagnetic energy (50) of high frequency and magnetic energy (H_{mod}) of lower frequency.

6. A tag according to any of claims 1-5, wherein the amorphous or nano-crystalline metal alloy of each magnetic element (31-36) has a majority ratio of cobalt.

7. A tag according to any of claims 1-6, wherein the composition of the amorphous or nano-crystalline metal alloy of each magnetic element (31-36) is $(Fe_{0.06}Co_{0.94})_{72.5}Si_{12.5}B_{15}$.

8. A method of encoding an identity code into an electronic article identification tag (30) having a plurality of magnetic elements (31-36), said identity code comprising a plurality of words at respective positions in a numeral system, each word being capable of storing one of *n* different values, **characterised** by the steps of

providing a first set of lengths (L) for magnetic elements;

providing a second set of diameters (D) for magnetic elements;

forming a third set of element types by associating one unique length among said first set of lengths (L), and one unique diameter among said second set of diameters (D), with each respective element type,

mapping each of said *n* different values to a respective element type;

providing a fourth set of angular positions (A) for magnetic elements;

arranging in said tag, for each word in said identity code, a magnetic element of the type corresponding to the value of the word, at one angular position among said fourth set of angular positions.

9. An article identification apparatus, where an individual article (20) is provided with a tag (30) comprising a plurality of angularly arranged magnetic elements (31-36), the apparatus comprising transmitter means (11, 13) for transmitting a first electromagnetic signal (50) in a detection zone (10); receiver means (12, 15) for receiving a second electromagnetic signal (60, 70), generated by the tag in response to the first electromagnetic signal from the transmitter means; modulating means (16) for generating a magnetic field (H_{mod}) for modulating the second electromagnetic signal during the generation thereof by the tag; demodulating means (15) for producing a reply signal (80) by demodulating the second electromagnetic signal (70) as received by the receiver means; and a controller (14) operatively connected to the demodulating means; characterized in that

the modulating means (16) is arranged to generate a magnetic modulating field (H_{mod}) having a rotating orientation, wherein the controller (14) is arranged to detect when a frequency shift occurs for the reply signal (80) and in response determine an angular position (α_i) of an individual magnetic element (i);

the modulating means (16) is arranged to generate a magnetic modulating field (H_{mod}) with increasing amplitude (ΔH_{ac}), wherein the controller (14) is arranged to determine a corresponding change in amplitude (ΔA) of the reply signal (80) and in response determine a length (L_i) of said individual magnetic element (i);

the modulating means (16) is arranged to generate a magnetic modulating field (H_{mod}) with increasing amplitude (H_{ac}), wherein the controller (14) is arranged to continuously monitor an amplitude of the reply signal (80) so as to detect a saturation point thereof and in response determine a diameter of said individual magnetic element (i); and

the modulating means (16) and the controller (14) are arranged to repeat the steps above for all magnetic elements (31-36) of the tag (30), wherein the controller (14) is arranged to determine an identity of the tag (30) from the angular positions (α_i), lengths (L_i) and diameters (ϕ_i) of the magnetic elements (31-36).

ABSTRACT

A tag (30) for electronic article identification has at least two magnetic elements (31-36), which represent an identity of the tag, or of an article to which the tag is attached. The magnetic elements may be electromagnetically detected and are formed as wires made from an amorphous or nano-crystalline metal alloy. The magnetic elements (31-36) are arranged at predetermined angles ($\alpha_1-\alpha_6$) to each other. At least one of the magnetic elements (31-36) has a length (L_1-L_6), which is different from the length of at least one other magnetic elements (31-36) of the tag. Furthermore, at least one of the magnetic elements has a diameter ($\phi_1-\phi_6$), which is different from the diameter of at least one other magnetic element of the tag. The lengths and diameters of the magnetic elements, and the angles between them, jointly form the identity of the tag.

To be published together with FIG 2.

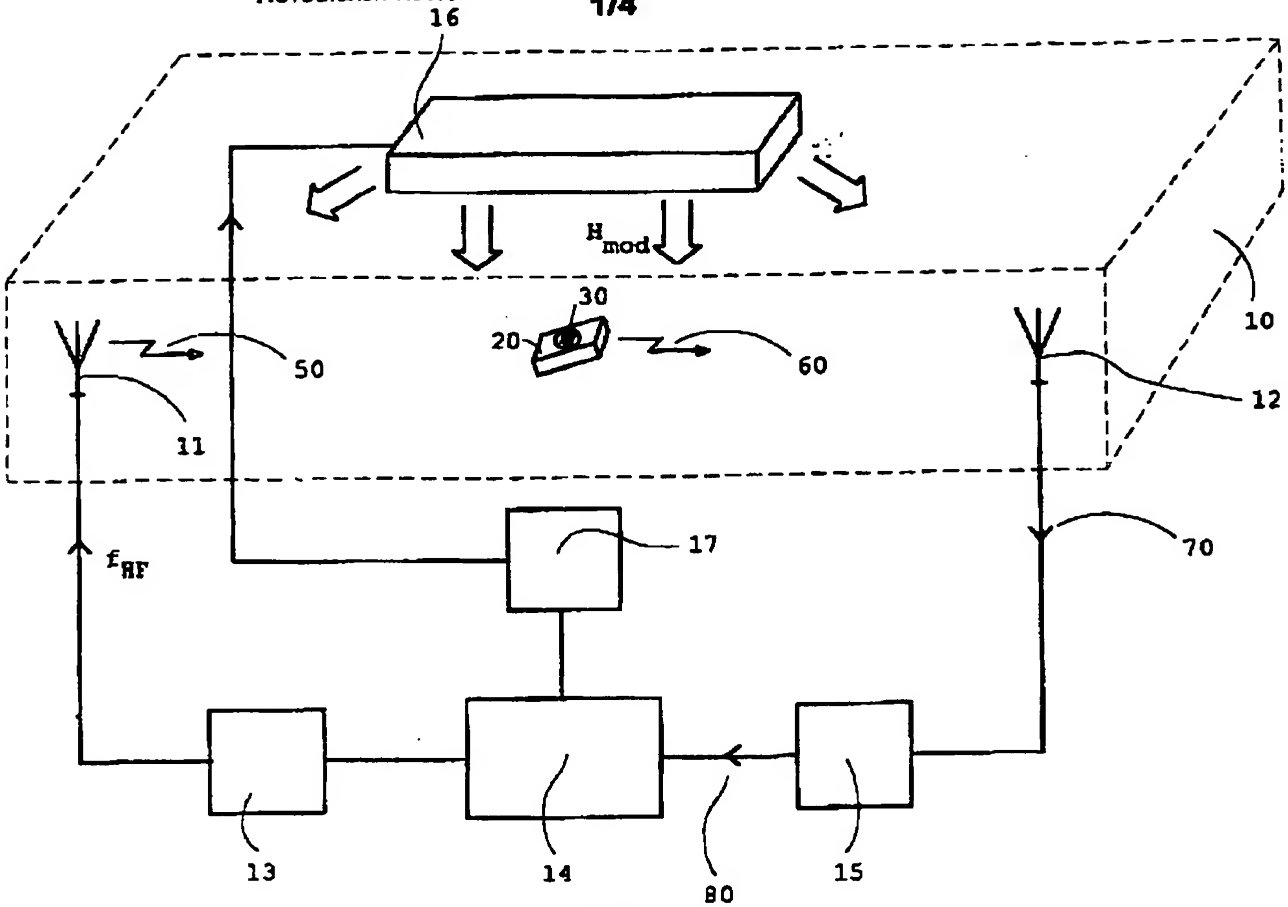
16
H mod
30
20
50
60
10
12
11
17
70
f_{HF}
13
14
80
15

FIG 1

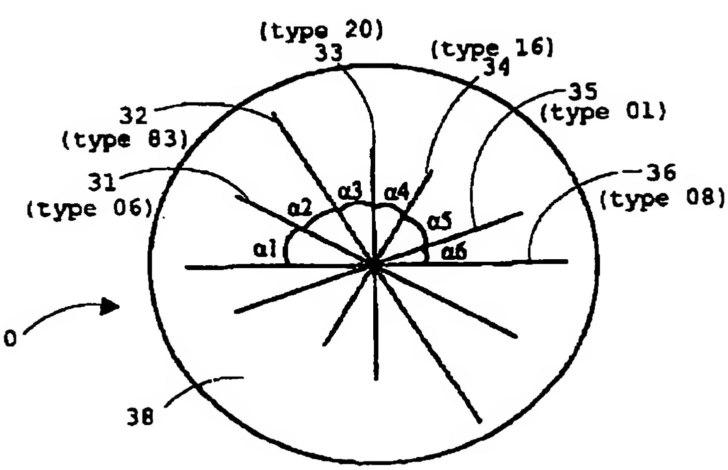
(type 20)
33
(type 16)
34
35
(type 01)
32
(type 83)
31
(type 06)
36
(type 08)
α1
α2
α3
α4
α5
α6
30
38

FIG 2

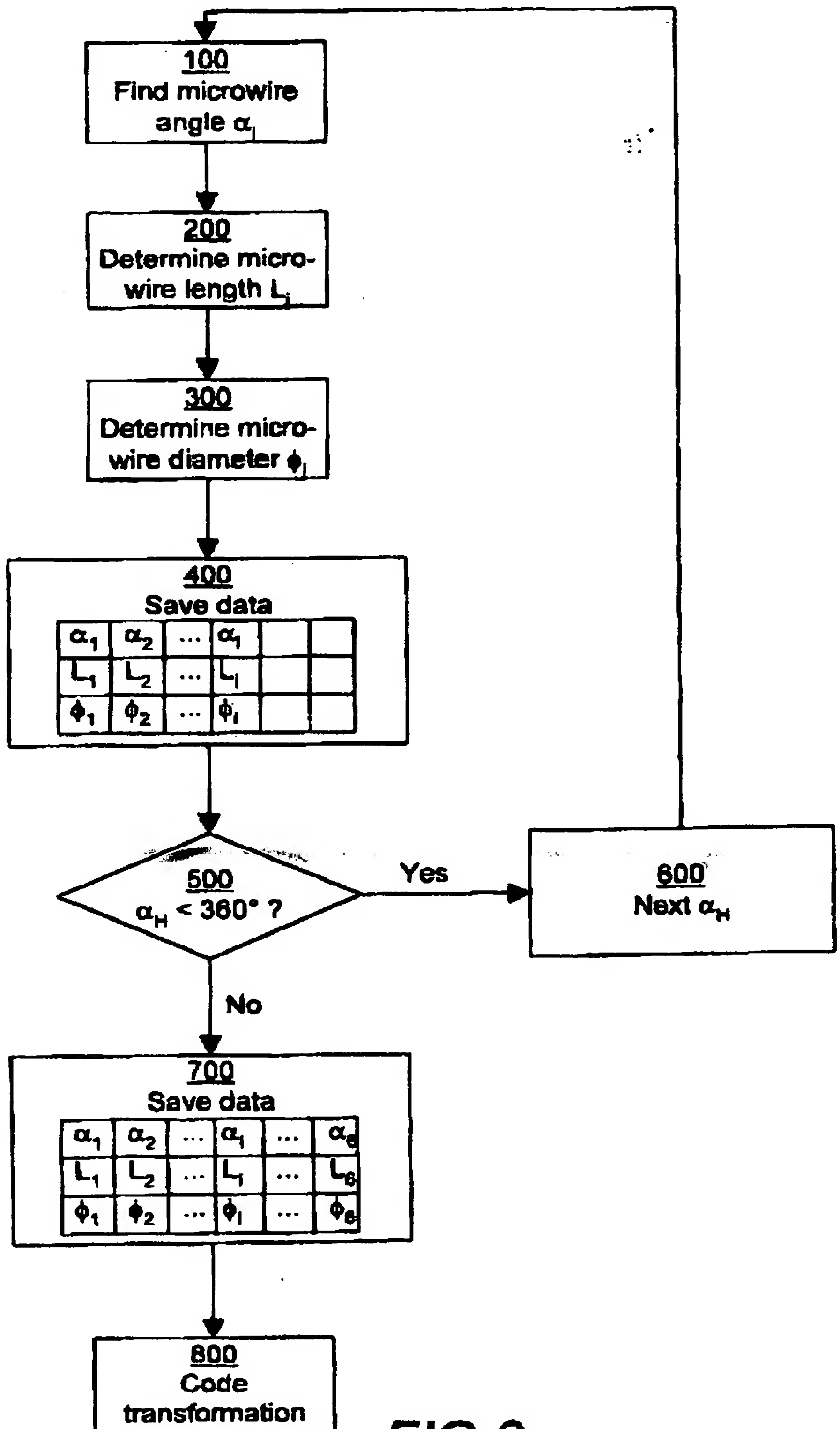
100
Find microwire angle α_i
200
Determine micro-wire length L_i
300
Determine micro-wire diameter ϕ_i
400
Save data
α_1 α_2 ... α_i
L_1 L_2 ... L_i
ϕ_1 ϕ_2 ... ϕ_i
500
$\alpha_H < 360°$?
Yes
No
600
Next α_H
700
Save data
α_1 α_2 ... α_i ... α_8
L_1 L_2 ... L_i ... L_8
ϕ_1 ϕ_2 ... ϕ_i ... ϕ_8
800
Code transformation

FIG 3

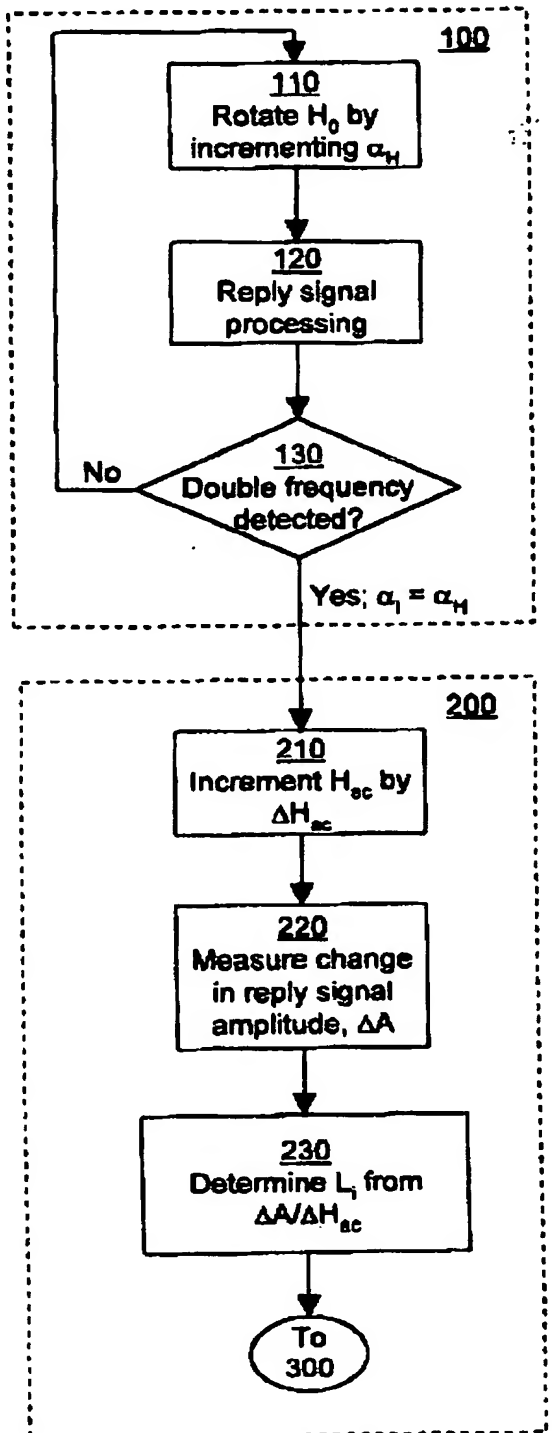
100
110
Rotate H_0 by incrementing α_H
120
Reply signal processing
130
Double frequency detected?
No
Yes; $\alpha_I = \alpha_H$
200
210
Increment H_{ac} by ΔH_{ac}
220
Measure change in reply signal amplitude, ΔA
230
Determine L_i from $\Delta A/\Delta H_{ac}$
To 300

FIG 4

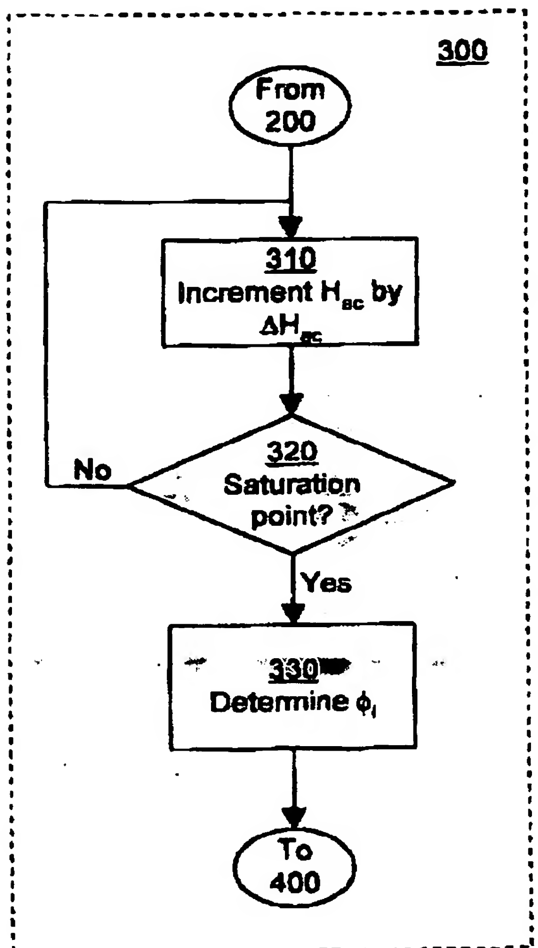
300
From 200
310
Increment H_{sc} by ΔH_{sc}
320
Saturation point?
No
Yes
330
Determine ϕ_i
To 400

FIG 5